UNIVERSITY of ROCHESTER

Roses:

Remote Online Sessions for Emerging Seismologists

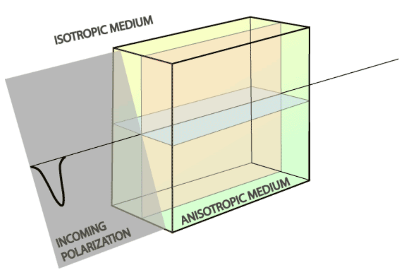
6: Polarization Analysis

Instructor: Tolulope Olugboji
TA: Ziqi (Evan) Zhang

Lecture: Tue, July 28; Meeting ID: 945 376 7030 Password: ROSES
Office Hour (@JoinZoom**)**

SLOW COVID-19

Key Ideas



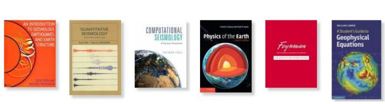
Animation of shear wave splitting upon entering an anisotropic medium. Courtesy of Ed Garnero. More @Wikepedia

More Help:

See @ROSESonSLack or @IRIS

References:

A variety: see @lecture



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Communication: Announcements will be made through blackboard. Please send emails sparingly. Grading

FALL, 2020

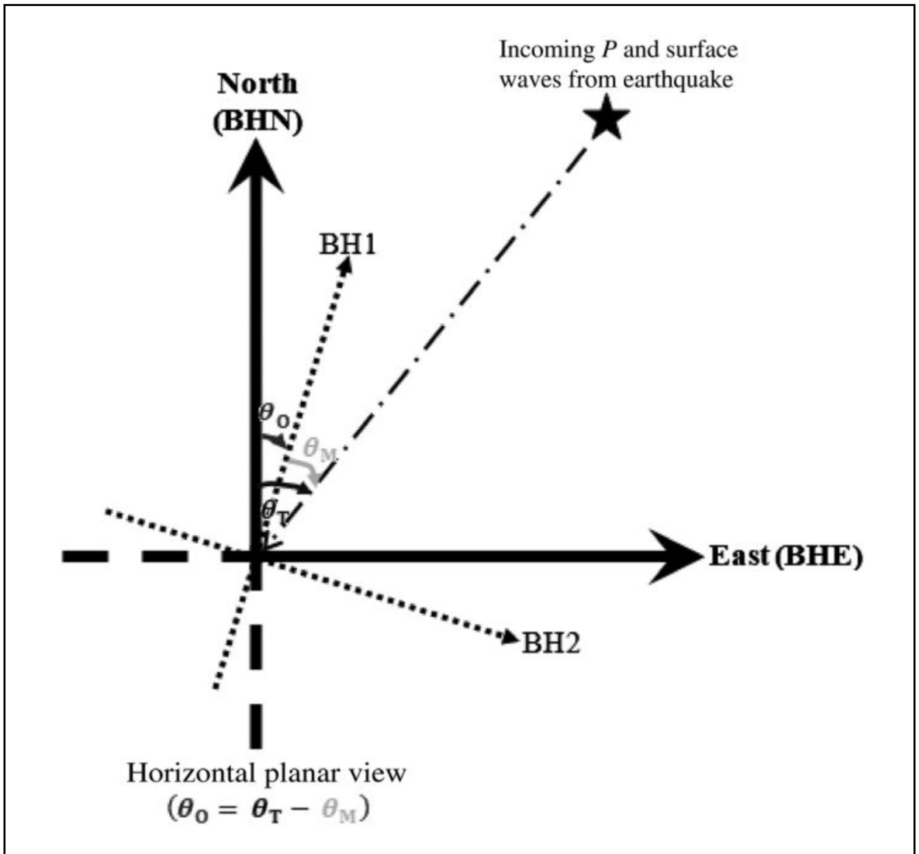
I. Overview - Learning Objectives

In this lab the student will learn how to ue

MATLAB scripts and data in @ZipFile

Exercise I - Arrival Direction of Earthquake (P Polarization)

The figure below describes how the correct horizontal orientation of a sensor can be deduced from the measured polarization azimuth of an incoming P wave or surface wave (Ojo et al. 2019). In their paper, which reviews a variety of standard techniques, the authors describe three ways of inferring the correct orientation.



Orientation of the horizontal seismometer for a left-handed coordinate system on an ideal Earth. BHZ emerges out of the page toward the reader, and the misaligned components are BH1, and BH2. The angles, $\theta_{O,T,M}$ represent the BH1 azimuth, true earthquake azimuth, and measured earthquake azimuth respectively.

Your objective is to use the technique of minimizing the transverse energy following rotation to the correct radial direction. First, download the three channel records from ocean bottom seismometer - station B13 here: @BHZ, @BH1 @BH2

Then use the equation to infer the measured earthquake azimuth in the radial direction.

through gradescope | @URSt @addTA

Miscellaneous:

Lower case Greek letters and commonly used capitals

α		alpha	ι		iota	ρ		rho
β		beta	κ		kappa	σ	Σ	sigma
γ	Γ	gamma	λ	Λ	lambda	τ		tau
δ	Δ	delta	μ		mu	υ	Υ	upsilon
ϵ		epsilon	ν		nu	ϕ	Φ	phi
ζ		zeta	ξ	Ξ	xi (ksi)	χ		chi (khi)
η		eta	o		omicron	ψ	Ψ	psi
θ	Θ	theta	π	Π	pi	ω	Ω	omega

(a) $\nabla \cdot (\nabla T) = \nabla^2 T =$ a scalar field

(b) $\nabla \times (\nabla T) = 0$

(c) $\nabla(\nabla \cdot \boldsymbol{h}) =$ a vector field

(d) $\nabla \cdot (\nabla \times \boldsymbol{h}) = 0$

(e) $\nabla \times (\nabla \times \boldsymbol{h}) = \nabla(\nabla \cdot \boldsymbol{h}) - \nabla^2 \boldsymbol{h}$

(f) $(\nabla \cdot \nabla)\boldsymbol{h} = \nabla^2 \boldsymbol{h} =$ a vector field

$$E_{\mathrm{T}}(\theta) = \frac{\sum_{i=1}^{N} w_i E_{\mathrm{T}}^{i}(\theta)}{\sum_{i=1}^{N} w_i}.$$

In this case since we have only one earthquake $i = 1 = N, and w_i = 1$, also the true earthquake azimuth is 280o and E_T should be the length of the transverse direction in the time window 2.5 minute to 4.0 minute. The data is sampled at 50 Hz.

Exercise II - Near Surface Velocity (P & S Polarization)

The figure below is taken from (Reading 2003, Rondenay 2009) and demonstrates coordinate transformations from the cartesian frame (ZRT) into two reference frames (i.e., LQT and PSH) that attempt to separate longitudinal and transverse seismic waves.

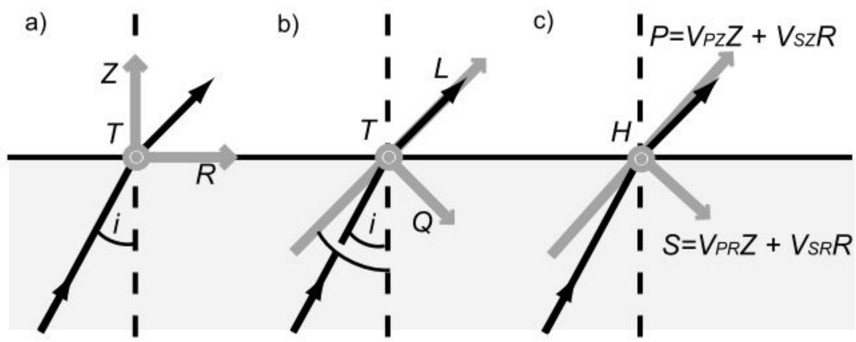


Figure 4.2: Seismic energy arriving at a receiver. a) station/event reference frame, ***ZRT***, b) ray coordinate reference frame, ***LQT***, and c) the ***PSH*** wavevector reference frame as used in this study. Incidence angle i

Using the transformation matrices below, and following from the general rotation and transformation matrices can you confirm the shear and compressional velocities have been fully separated used to generate tthis sysnthetic waveform @Rondenay2019_syntrace.txt ?

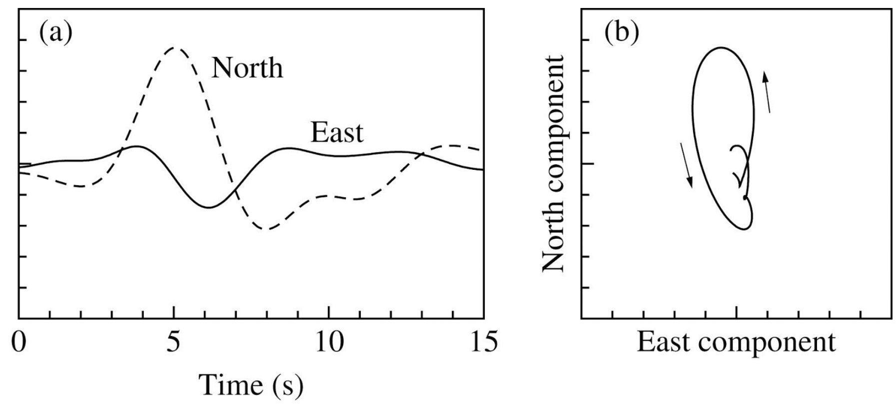
$$\begin{pmatrix} P \\ SV \\ SH \end{pmatrix} = \begin{pmatrix} \frac{\beta^2 p^2 - 1/2}{\alpha q_\alpha} & \frac{p\beta^2}{\alpha} & 0 \\ p\beta & \frac{1/2 - \beta^2 p^2}{\beta q_\beta} & 0 \\ 0 & 0 & 1/2 \end{pmatrix} \begin{pmatrix} Z \\ R \\ T \end{pmatrix}, \begin{pmatrix} L \\ Q \\ T \end{pmatrix} = \begin{pmatrix} \cos i_\alpha & \sin i_\alpha & 0 \\ -\sin i_\alpha & \cos i_\alpha & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} Z \\ R \\ T \end{pmatrix},$$

The synthetic waveforms are constructed using the RAYSUM package ((Frederiksen and Bostock 2000) for an incident P-wave with backazimuth γ =30° and a ray parameter p = 0.08 s/km, recorded at a single surface location. The model sampled by the incident wave is isotropic, and consists of a 40 km-thick horizontal layer ($\alpha 0$ = 6.0 km/s, $\beta 0$ = 3.4 km/s, $\rho 0$ = 2,600 kg/m3) over a half-space ($\alpha 1$ = 8.1 km/s, $\beta 1$ = 4.5 km/s, $\rho 1$ = 3,500 kg/m3)

Exercise III - Anisotropy & Shear Wave Splitting (@Shearer3rdEd)

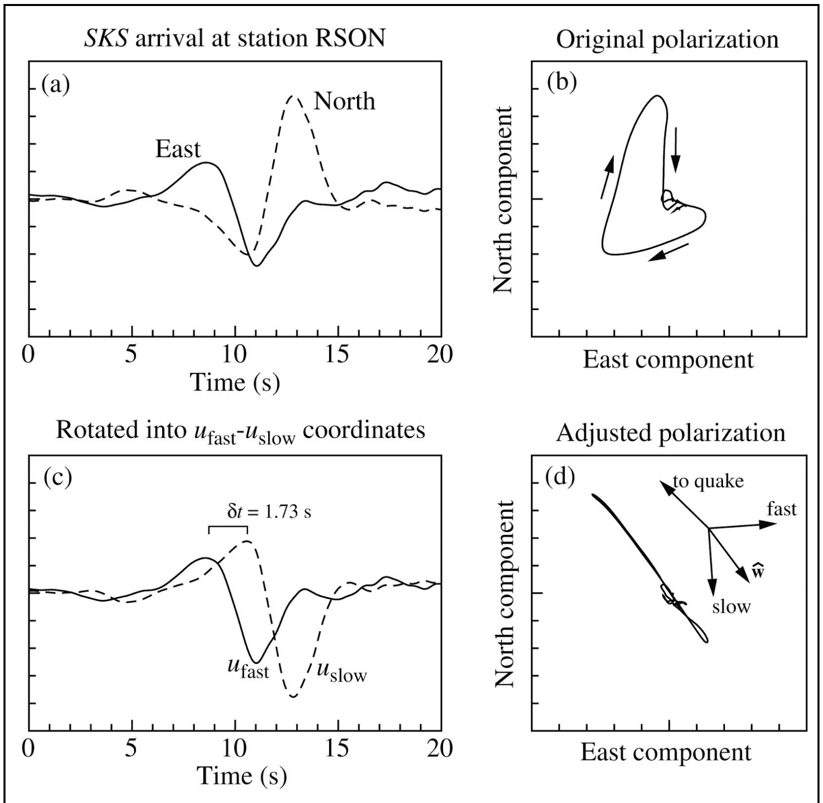
The figure below plots an SKS arrival recorded at the Canadian station ILON for a 2006/8/25 earthquake at 94o epicentral distance and at an azimuth (clockwise from north) of 166o (at ILON to the quake). Seismograms for the east and north components (20 samples/s) can be downloaded from link: @ILON_data.txt (data courtesy Ian Bastow, see also Darbyshire et al., 2013).

1. Read in the data and produce your own version of the plots below



SKS phase recorded at station ILON. (a) The east and north seismometer components. (b) Horizontal particle motion, arrows show trajectory.

2. Using the covariance matrix method for shear-wave splitting analysis, solve for the fast-axis orientation, ϕ, and delay time, δt, tha yields the maximum eigenvalue ratio λ_1/λ_2. What are ϕ, and δt? What is the azimuth of the eigenvector associated with the largest eigenvalue and how does it compare to the radial direction?
3. Using these results, plot the u_{fast} and u_{slow} pulses and the model-corrected participle motion (see example case below)



Example of shear-wave splitting analysis. (a) The east and north seismometer components. (b) Horizontal particle motion, arrows show particle trajectory. (c) Seismograms rotated into fast and slow polarization directions. (d) Horizontal particle motion, after correction for anisotropy model. Fast and slow directions, covariance matrix principal eigenvector direction $\hat{\mathbf{w}}$, and azimuth to earthquake are also shown

4. Using the minimum transverse energy method for shear-wave splitting analysis, solve for the fast-axis orientation, ϕ, and delay time, δt, that yields the least transverse energy in the model-corrected motion. What are ϕ, and delay time, δt, in this case?
5. Using the results, plot the u_{fast} and u_{slow} pulses and the model-corrected participle motion .
6. What factors might account for the differences between your results for the two methods? Which method do you think is better for this case?

Exercise IV - Single Station Quake Location or HV Ratios: (Rayleigh Wave Polarization)

Show simple synthetics here

Further reading [(Vecsey et al. 2008)](#)

Supplemental Texts

1. Stein, S. & Wysession, M. *An Introduction to Seismology, Earthquakes, and Earth Structure*. (John

Wiley & Sons, 2009).
2. Igel, H. *Computational Seismology: A Practical Introduction*. (Oxford University Press, 2017).
3. Aki, K. & Richards, P. G. *Quantitative Seismology*. **II,** 700 (University Science Books, 2002).
4. Stacey, F. D., Davis, P. M. & Others. *Physics of the Earth*. **2,** (Wiley New York, 1977).
5. Lowrie, W. *A Student's Guide to Geophysical Equations*. (Cambridge University Press, 2011).
6. Feynman, R. P., Leighton, R. B. & Sands, M. *The Feynman Lectures on Physics, Vol. I: The New Millennium Edition: Mainly Mechanics, Radiation, and Heat*. (Basic Books, 2011).
7. A Student's guide to Waves by Fleisch & Kinnaman [online]
8.